Advanced Technology Microwave Sounder on NPOESS and NPP

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Abstract - The Advanced Technology Microwave Sounder (ATMS) is under development by NASA GSFC. The first ATMS flight unit will fly on the NASA, NPOESS Preparatory Project (NPP) satellite, and ATMS production units will be part of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) sensor suite. This paper presents key instrument design features, channel characteristics, predicted performance, recent development status and the NPOESS plan for ATMS.

I. INTRODUCTION

The Advanced Technology Microwave Sounder (ATMS) is a new generation microwave instrument being developed for NPOESS. It will improve the temperature and humidity sounding performances over the current generation of microwave sounders. The ATMS is a follow-on instrument to the Advanced Microwave Sounding Unit (AMSU), currently flying on NOAA satellites. The primary new ATMS features are a reduced hardware package and improved gap coverage and spatial resolution. NASA/GSFC is responsible for development costs and the first prototype flight unit, and NPOESS is responsible for future production units. Northrop Grumman Electronic Systems (NGES), Azusa, CA, is the ATMS primary contractor. The first flight unit will fly on the joint NPOESS/NASA NPP mission as an environmental mission for NASA, and a risk reduction mission for NPOESS. Future production units will fly on NPOESS satellites.

The ATMS will provide global atmospheric temperature and humidity profiles. Temperature and humidity profiles are best measured using both microwave and infrared (IR) sounders together. The ATMS will work with the Cross-track Infrared Sounder (CrIS), which will also be flown aboard the NPP and NPOESS satellites. The IR and microwave sounders complement each other. IR sounders provide better spatial resolutions, but they do not function well in cloudy regions, those that are most interesting for weather forecasting purposes. Microwave sounders, on the other hand, generally have poorer spatial resolutions, but because they use longer wavelengths, their performance is not diminished by most cloud conditions encountered.

II. ATMS INSTRUMENT DESIGN

Figure 1 provides a block schematic diagram showing the subsystems of the ATMS. Beginning with the front-end microwave optics, the 22 channels of the ATMS are divided into two groups: a low-frequency (24 to 57 Ghz) group, and a high-frequency (88 to 183 Ghz) group. The low-frequency channels, 1 through 15, are primarily for temperature soundings and the high-frequency channels, 16 through 22, are primarily for humidity soundings. Each group has an antenna aperture followed by a diplexing subsystem to further separate the channels. However, the two antennas are joined together mechanically and are driven by a single scan-drive motor with its associated control electronics. The single scanner design is necessary in order to accommodate the available small volume of approximately 40 cm x 60 cm x 70 cm.

The microwave emissions from the atmosphere entering the antenna apertures are first reflected by a scanning, flat-plate reflector to a stationary parabolic reflector, which focuses the energy to a feed-horn. Behind the feedhorn, Channels are frequency-diplexed into separate channels and amplified by a Low-Noise-Amplifier (LNA). The output of the LNA is fed though a band-pass filter and to a detector. The detected signal is integrated and routed to the Signal Processor for buffering and transferring to the spacecraft and beyond.

III. ATMS CHANNEL CHARACTERISTICS

Table 1 shows the channel characteristics and some of the important parameters of the ATMS. The ATMS contains all of the channels of AMSU-A and AMSU-B, plus several additional new channels. The asterisk next to the channel number signifies a new channel, or that its frequency is different from the AMSU.

The center frequencies of the temperature sounding channels of the ATMS, i.e., Channels 3 through 15, are nearly identical to that of the AMSU-A; only Channel 4 is a new addition. Channels 1 and 2 provide water vapor and surface emissivity information needed for temperature profile retrieval. All the temperature channels are clustered in the lower part of the 50 to 58 Ghz atmospheric oxygen band. Figure 1 shows the locations of the ATMS channels superimposed on the capacity curves of the atmospheric oxygen and water vapor absorption lines.

Most of the center frequencies of the temperature sounding channels are located at the “valleys” between two absorption lines, where the opacity changes (versus frequency) very slowly. By setting the center frequency of a channel at such a location, the instrument can use much of bandwidth, thus improving the signal-to-noise ratio, but without broadening the vertical resolution of that channel.

Channels 16 to 20 form the humidity-sounding group. Most of these channels are clustered about the strongly opaque water vapor line at 183.3 Ghz. Channels 18 to 22 have two pass-bands. These pairs of pass-bands are located symmetrically about the peak of the 183.3 Ghz line so that the opacity values of each pass-band is about the same. Channel 17 is equivalent to the 150 Ghz channel of the AMSU-B, except the center frequency has been moved to a new location for better spectrum protection. Channels 19 and 21 are two additional channels in this group, from the AMSU-B. These new channels will enhance the humidity profiling performance.

IV. ON-BOARD CALIBRATION AND ANTENNA SCAN PATTERN

The ATMS relies of the stability of its electronics gain and frequent on-board calibrations to maintain calibration accuracy. The on-board calibration of the ATMS is a through-the-aperture type, two-point calibration subsystem. The warm reference point is a microwave blackbody target whose temperature is monitored. The cold reference point is the cosmic background radiation. These features are similar to the AMSU design. New features introduced in the ATMS are primarily in the hardware packaging, and the fact that ATMS has only two warm targets to cover all of its 22 channels, with frequency ranging form 23 to 190 Ghz. The antenna scanner rotates (in a counter clock-wise direction, looking along the spacecraft velocity vector) one complete 360 degree revolution in 2.67 seconds. A major portion of the scan period is spent in receiving data from the Earth and executing the warm and cold calibrations. The scanning angular speed is constant during the Earth viewing and calibration periods. The antenna accelerates as it moves from one direction to another.

There are three antenna beam-widths. The temperature sounding channels are 2.2 degrees and the humidity channels are 1.1 degrees. Channels 1 and 2 have a larger beam width of 5.2 degrees. This is due to the limited volume available on the spacecraft on the spacecraft for the ATMS. The ATMS contractor, NGES, is required to develop Sensor Data Record re-sampling algorithms that can produce estimates of microwave brightness temperature at the location of the CrIS field-of-regard centers and have an effective, CrIS-like, 3.3 degree field-of-view for all ATMS channels. The method and degree of re-sampling is currently a topic of discussion among the NPP and NPOESS science community.

V. ENGINEERING DEVELOPMENT UNIT AND PERFORMANCE PREDICTIONS

By June, 2004, the ATMS Engineering Development Unit (EDU) had successfully completed integration and a series of functional and environmental tests including Thermal Balance, Calibration Accuracy, Thermal Vacuum Cycling, Vibration and Antenna Verification. Radiometric performance and calibration accuracy were measured in these tests. Table 2 provides a summary of ATMS Technical Performance Measures projected for the initial Flight Unit that is scheduled to fly on the NPP spacecraft. Table 2 lists the key ATMS parameter, the specification value, the projection and the basis for the projection. The bases for projections include measurements from the EDU during testing, measurements from the Flight Unit and analysis using predictive models. Table 2 shows that all key parameters are projected to meet specifications. Table 3 provides the predicted temperature sensitivity, NEdT, for the NPP Flight Unit. Nominal and worst case predictions are provided. Worst-case predictions are derived from recent supplier data and worst-case component specification limits. Nominal case predictions are derived from EDU test data. Table 3 shows that all channels are predicted to meet NEdT specifications. These performance predictions were independently verified by three separate models at NGES and MIT Lincoln Labs. Table 4 shows Flight Unit predicted Calibration Accuracy based on EDU Thermal Vacuum calibration measurements. Table 4 shows that the ATMS flight module is predicted to meet Calibration Accuracy performance requirements with a 37%-60% margin relative to requirements.

VI. DEVELOPMENT STATUS

A GSFC Phase A Study determined that the ATMS could be built with approximately one-third of the volume, mass, and power compared to it's predecessor, AMSU, with equal or better performance. These goals have proven to be a difficult challenge for the ATMS development. The most challenging of these goals have been development of a newly designed smaller and lighter Scan Drive System, and development of advanced Monolithic Microwave Integrated Circuit (MMIC) technology for the Front End Radio Frequency Modules. A recent ATMS review indicated that the primary technical issues have been resolved and major development risks have been retired. Recent development accomplishments include, 1) the ATMS EDU has successfully completed integration and a series of functional and environmental tests, 2) the first Scan Drive System has been delivered and tested in the EDU instrument, 3) an updated Scan Drive Electronics subsystem control algorithm for the Flight Unit has been successfully completed, 4) alternate Gunn Diode solutions for Phase Locked Oscillators have been developed, and 5) an alternate MMIC has been implemented to improve Channel 16 performance so that it now is expected to meet the contractual specification (as are all other channels). The ATMS NPP Flight Unit is on-track for a March, 2005 delivery to the NPP Spacecraft for test and integration. This schedule provides a two-month margin to the current NPP spacecraft Integration and Test need date of June, 2005.

VII. SUMMARY

The ATMS will be a key instrument for the NPOESS polar-orbiting weather satellites in the next couple of decades. In conjunction with the CrIS, the improved accuracy in atmospheric temperature and humidity soundings, in combination with observations from other NPOESS instruments, will enable weather forecasts to be significantly improved over the next decade. Development challenges have been difficult for the ATMS due to the reduced volume, mass and power requirements. In addition, lifetime requirements are more severe due to the longer program span and required orbital life for NPOESS. Based on the latest development status, ATMS is successfully meeting these challenges. The initial ATMS Flight Unit will fly on the NPP Spacecraft, currently planned for launch in October, 2006. For NPOESS, the ATMS is slated to fly on the morning and afternoon orbits. The latest NPOESS schedule shows the ATMS to fly on the initial NPOESS spacecraft slated for launch in November, 2009. Pending developments for the POESS N' spacecraft and a potential new LandSat instrument, that may fly on NPOESS, may alter these plans.

REFERENCES

[1] Shiue, James C., "The Advanced Technology Microwave Sounder, a New Atmospheric Temperature and Humidity Sounder for Operational Polar-Orbiting Weather Satellites" Proceedings of SPIE Vol. 4540, 2001.

ATMS Channel Characteristics
TABLE 1

Channel	Center Frequency (GHz)	Maximum Bandwidth (GHz)		Temperature Sensitivity (K) NEΔT	Calibration Accuracy	Static Beamwidth B (degrees)	Characterization at Nadir
1	23.8	0.27		0.9	2.0	5.2	window-water vapor 100 mm
2	31.4	0.18		0.9	2.0	5.2	window-water vapor 500 mm
3	50.3	0.18		1.20	1.5	2.2	Window-surface emissivity
4*	51.76	0.40		0.75	1.5	2.2	Window-surface emissivity
5	52.8	0.40		0.75	1.5	2.2	surface air
6	53.596 $\pm$ 0.115	0.17		0.75	1.5	2.2	4 km ~ 700 mb
7	54.40	0.40		0.75	1.5	2.2	9 km ~ 400 mb
8	54.94	0.40		0.75	1.5	2.2	11 km ~ 250 mb
9	55.50	0.33		0.75	1.5	2.2	13 km ~ 180 mb
10	57.2903	0.33		0.75	1.5	2.2	17 km ~ 90 mb
11	57.2903 $\pm$ 0.115	0.078		1.20	1.5	2.2	19 km ~ 50 mb
12	57.2903	0.036		1.20	1.5	2.2	25 km ~ 25 mb
13	57.2903 $\pm$ 0.322	0.016		1.50	1.5	2.2	29 km ~ 10 mb
14	57.29 $\pm$ 0.322 $\pm$ 0.010	0.008		2.40	1.5	2.2	32 km ~ 6 mb
15	57.29 $\pm$0.322 $\pm$0.004	0.003		3.60	1.5	2.2	37 km ~ 3 mb
16	87-91 (88.20)	2.0		0.5	2.0	2.2	Window H O 150 mm

17 *	164-167	3.0		0.6	2.0	1.1	H_2O 18 mm
18	183.31 ± 7	2.0		0.8	2.0	1.1	H_2O 18 mm
19 *	183.31 ± 4.5	2.0		0.8	2.0	1.1	H_2O 4.5 mm
20	183.31 ± 3	1.0		0.8	2.0	1.1	H_2O 2.5 mm
21	183.31 ± 1.8	1.0		0.8	2.0	1.1	H O 1.2 mm
22	183.31 ± 1.0	0.5		0.9	2.0	1.1	H_2O 0.5 mm

ATMS Technical Performance Measures, June 04
TABLE 2

Key Parameter	Spec Value	Projection	Basis
Cal Accuracy (K)	< 0.75	< 0.41	Analysis, with partial measurements validation
Nonlinearity (K)	< 0.10	< 0.088	Worst-case EDU measurement + analysis
Beam Efficiency (%)	> 95	> 95	Analysis, with partial measurement validation
Freq. Stability (MHz)	< 0.50	0.45	Measurement + analysis
Pointing Knowl. (deg)	< 0.05	0.044	Analysis
Mass (kg)	< 85	75.4	Measurement
Power (W)	< 110	91.0	Measurement
Data rate (kbps)	< 30	28.9	Measurement
Reliability	> 0.86	0.88	Analysis

TABLE III: ATMS PERFORMANCE –
PFM PREDICTED NEΔT

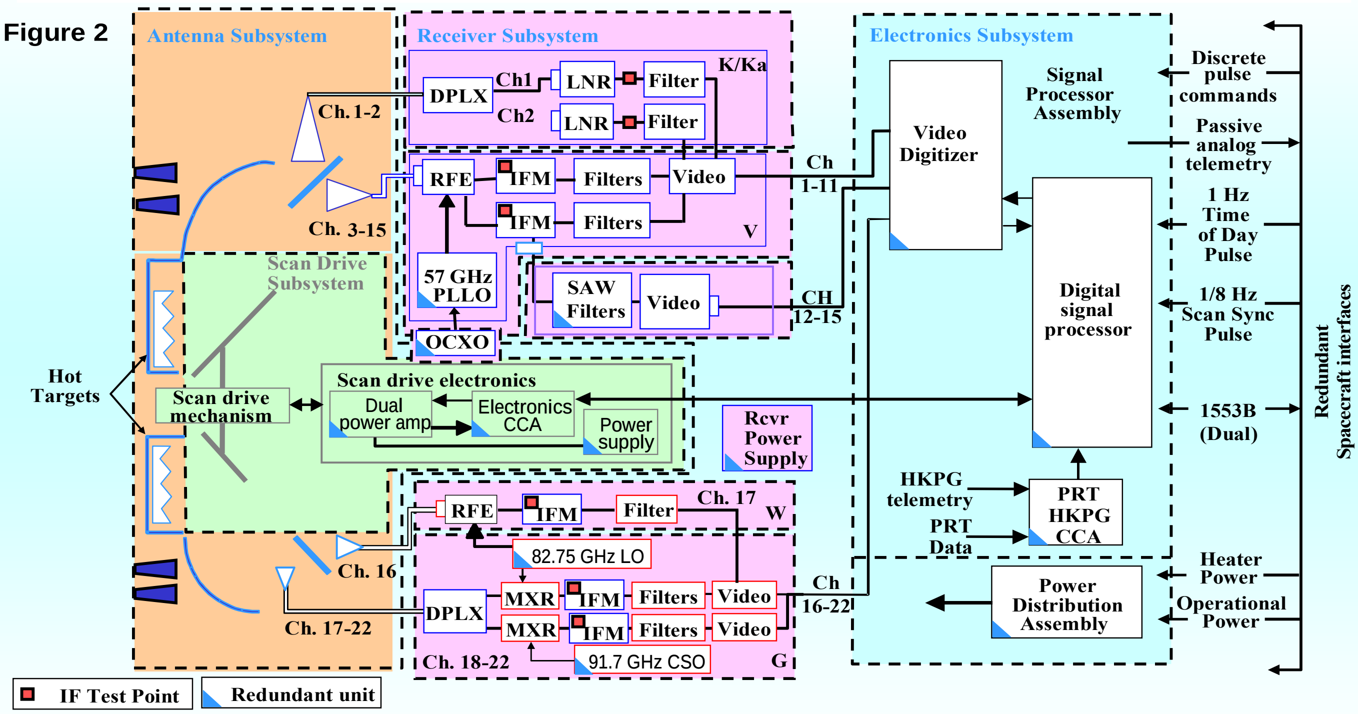
		Nominal Case		Worst Case	
CH	**Req't (K)**	**NEΔT (K)**	**Margin (%)**	**NEΔT (K)**	**Margin (%)**
1	0.50	0.31	37.6	0.34	32.1
2	0.60	0.8	36.8	0.42	30.4
3	0.70	0.51	26.8	0.54	23.3
4	0.50	0.37	25.3	0.38	23.5
5	0.50	0.38	24.0	0.39	22.7
6	0.50	0.40	19.5	0.41	18.0
7	0.50	0.43	14.5	0.42	16.6
8	0.50	0.43	14.5	0.42	16.6
9	0.50	0.45	9.8	0.44	11.2
10	0.75	0.62	17.6	0.63	15.8
11	1.00	0.83	16.5	0.87	12.6
12	1.00	0.90	10.3	0.96	4.1
13	1.50	1.33	11.0	1.42	5.3
14	2.20	1.82	17.2	1.96	11.0
15	3.60	2.99	17.0	3.25	9.7
16	0.30	0.28	7.2	0.30	0.0
17	0.60	0.57	5.2	0.59	1.5
18	0.80	0.47	40.8	0.45	43.8
19	0.80	0.48	40.4	0.45	43.3
20	0.80	0.57	28.6	0.56	29.7
21	0.80	0.58	27.0	0.58	27.7
22	1.90	0.75	16.3	0.76	15.0

TABLE IV: ATMS PERFORMANCE – PFM PREDICTED
CALIBRATION ACCURACY

Accuracy (K)				
CH	**Req't**	**Predict**	**Margin**	**Margin (%)**
1	1.00	0.627	0.37	37.3
2	1.00	0.627	0.37	37.3
3	0.75	0.406	0.34	45.9
4	0.75	0.406	0.34	45.9
5	0.75	0.406	0.34	45.9
6	0.75	0.406	0.34	45.9
7	0.75	0.406	0.34	45.9
8	0.75	0.406	0.34	45.9
9	0.75	0.406	0.34	45.9
10	0.75	0.406	0.34	45.9
11	0.75	0.406	0.34	45.9
12	0.75	0.407	0.34	45.7
13	0.75	0.407	0.34	45.7
14	0.75	0.407	0.34	45.7
15	0.75	0.407	0.34	45.7
16	1.00	0.410	0.59	59.0
17	1.00	0.401	0.60	59.0
18	1.00	0.402	0.60	59.8
19	1.00	0.402	0.60	59.8
20	1.00	0.401	0.60	59.9
21	1.00	0.401	0.60	59.9
22	1.00	0.401	0.60	59.9

ATMS Functional Block Diagram

Figure 2



ATMS Channels and Frequencies

Figure 1